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(54) Multifocal multizone diffractive ophthalmic lenses

Multifokallinsen mit Diffraktionszonen

Lentilles multifocales à plusieurs zones diffractives

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Description

The present invention relates to multifocal lenses for correcting vision and, more specifically relates to bifocal lenses having at least one diffractive zone which is added to the basic refractive power of the lens.

BACKGROUND OF THE INVENTION

Ophthalmic lenses which have two or more distinct focal lengths are known. Such lenses have been used in the past as contact lenses which are disposed upon the surface of the eye, or as intraocular lenses (IOL's) which are surgically implanted to replace the natural crystalline lens after its removal during, e.g., cataract surgery. Diffractive lenses are well known within the field of optics generally, however they have as yet found only limited application to intraocular or contact lens design. Thus, although numerous designs have been disclosed for multifocal optics for use in contact or intraocular lenses, few have been found to be in any way practical.

Lenses relying solely upon refraction have been disclosed. For example, U.S. Patent 4,636,211--Nielsen, et al. discloses a bifocal intraocular lens which has concentrically oriented near vision and far vision zones achieved by refraction, the central zone adapted for near vision and surrounded by a coaxial far vision zone. The lenses disclosed have either a plano-convex or bi-convex shape. U.S. Patent 4,813,955--Achatz et al. discloses a multifocal intraocular artificial ophthalmic lens divided into near range and far range zones disposed symmetrically about the lens axis which uses the refractive power of the lens material and its shape to achieve bi-focal vision.

Designs of contact lenses which rely only upon the refractive properties of the Fresnel lens are also known. For example, U.S. Patent 4,162,122--Cohen discloses a zonal bifocal contact lens comprised of a concave spherical or aspherical posterior surface and a continuous anterior surface which is divided into concentric annular rings which are alternately inclined to the optical axis, corresponding to curvatures appropriate for the near and distant foci. The interfaces of the annular zones are continuous and do not create any steps or jumps on the anterior surface. Each zone consists of a refractive element only, the zones forming a smooth anterior surface.

Lenses utilizing the combined properties of Fresnel lenses and Fresnel zone plates and which rely on the diffractive effects thereof are also known. U.S. Patent 4,210,391--Cohen discloses multifocal optical lenses which have their multifocal properties distributed throughout the lens. The lenses disclosed share the incident light between the focal points by using a zone plate and splitting the incident light into discrete "bundles" each directed to a particular focal point. The design utilizes elements of both a Fresnel lens and a Fresnel zone plate, relying on the fact that such optical elements are comprised of concentric rings or zones and thus provides lens designs having reduced diffractive and chromatic aberrations. U.S. Patent 4,338,005--Cohen also discloses a multifocal phase plate lens design which has multifocal properties distributed throughout the lens. The lens disclosed is comprised of concentric zones, the diameters of which are derived from the focal length desired and wavelength of light being focused. The performance of the lens is not degraded by the superposition of blurred images at the focal points. Also, U.S. Patent 4,340,283--Cohen discloses a multifocal zone plate construction suitable for use in optical systems with multifocal requirements. A phase shift multifocal zone plate provides multiple foci by adjusting the zone plate spacings such that the zone plate foci coincide with multifocal Fresnel lens foci. The adjustment is obtained by ion implantation in certain sections of the lens, whereby the refractive index of the lens is altered in that section.

Additionally, others have attempted to combine both refractive and diffractive powers to create multifocal lenses. U.S. Patent 4,673,697--Freeman discloses multifocal contact lenses utilizing diffraction and refraction by adding diffractive power to the basic refractive power of the lens. The diffractive power is provided by a series of concentric zones defined by surface discontinuities or refractive index changes. In a bifocal application, diffractive power is provided in addition to the basic refractive power of the lens, while maintaining the basic curvature of the front and rear surfaces. The diffractive zones deviate all of the incident light in the manner of a phase zone plate (Fresnel zone plate). The '697 Freeman patent teaches that it is important to maintain the radius of curvature of the rear surface of the lens at a value which will maintain close conformance with the cornea. U.S. Patent 4,642,112--Freeman discloses bifocal artificial eye lenses which utilize a transmission hologram to provide diffractive power on a wavelength or amplitude selective basis in a manner which is additive to the basic refractive power of the lens.

When a diffraction element is used to provide two separate focal lengths, the maximum theoretical efficiency results in about 40.5% of the incident light forming an image at each focal distance. This is known e.g. from EP-A-0 316 162 and EP-A-0 343 067. Therefore, the overall total efficiency of the lens is about 81%. The remainder of the light (about 19%) is scattered into higher order diffraction patterns and thus degrades the images formed, rather than enhancing them. Therefore, it would be desireable to provide multifocal lenses which utilize both diffractive and refractive elements and which exhibit an overall total efficiency closer to an ideal 100%.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a highly efficient multifocal lens. Accordingly,

the present invention, as specified in Claim 1, provides increased efficiency multifocal lenses by using at least one diffractive zone located in a defined portion of the surface of a refractive lens. The lenses of a first embodiment of the present invention are thus divided into two areas, a first area of highly efficient diffractive power and a second area having essentially no diffractive power. Most preferably, the diffraction zones provide substantially 100% efficiency in the +1 diffractive order. The non-diffractive zones allow light to be transmitted without appreciable deviation due to diffraction. Most preferably, the zones are of about equal area, thereby causing about one-half of the incident light to focus at each of the two focal planes, resulting in an overall lens efficiency approaching 100%.

In another preferred embodiment, as specified in Claim 11, lenses are provided which have two different diffractive elements disposed substantially across the entire lens surface. The two diffractive patterns are different in that they have different diffractive powers. Since the diffractive powers are additive to a basic lens power provided by the lens upon which the diffractive elements are disposed, a multifocal lens having adequate power and high efficiency is achieved. For example, highly efficient zones having diffractive powers of about 10 diopters and 14 diopters can be provided for distance and near vision respectively. These diffractive powers are additive to the refractive basic power of the lens upon which they are disposed, e.g., a 10 diopter biconvex lens. Thus, in this example, 20 diopters of optic power are provided for distance vision and 24 diopters are provided for near vision. Since the diffractive zones are preferably high efficiency diffractive elements, a bifocal lens is provided which approaches 100% efficiency.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a graph of the optical efficiency of a diffractive lens element.

FIG. 2 is a plan view of a preferred embodiment of a lens made in accordance with the present invention which has two diffractive elements divided into an annular and a circular zone.

FIG. 3 is a plan view of another preferred embodiment of a lens made in accordance with the present invention which has a single diffractive element comprised of an annular zone.

FIG. 4 is a plan view of a preferred embodiment of the present invention which has two diffractive elements each divided into two zones.

FIG. 5 is a plan view of an intraocular lens made in accordance with the present invention which has a far vision zone and a near vision zone defined by bisecting the lens.

FIG. 6 is a plan view of an intraocular lens made in accordance with the present invention which has a far vision zone and a near vision zone defined by dividing the lens into quadrants.

FIG. 7 is a schematic representation of the passage of light through a bi-focal intraocular lens made in accordance with the present invention.

FIG. 8 is a schematic representation of the passage of light through a bi-focal contact lens made in accordance with the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention presents numerous advantages over the prior designs discussed above. Primarily, the present invention increases the overall aggregate efficiency of the lens. Ideally, 50% of the incident light is provided to each focal point. One image is created from distant objects and one image is created from near objects. The increased efficiency of the lenses of the present invention provide the maximum possible image contrast and resolution. Preferably the high efficiency diffraction zone has an optical efficiency of the greatest practical value, i.e., about 98%. In a preferred embodiment, a high efficiency diffraction grating is produced. Since about 98% of the light that passes through the diffractive zones will be focused on the retina for near objects and substantially all of the light that passes through the refractive zones will be focused on the retina for distant objects, improved multifocal vision is achieved. The present invention therefore overcomes the problem of unwanted light scattering caused by higher diffractive orders. Thus, lenses of the present invention have a higher potential efficiency than any known prior art design.

As set forth above, the maximum theoretical efficiency available from a standard phase zone plate is about 81%. The intermittent diffractive/non-diffractive construction of the present invention has the potential to exhibit considerably higher efficiencies. The efficiency, of a diffractive lens element, as a percentage of transmitted light, is shown graphically in FIG. 1. The efficiency is plotted against the step height, in microns, on the lens surface for a silicone lens in water. A first plot line 50 depicts the efficiency of the 0th (zeroth) order diffraction. A second plot line 52 depicts the efficiency of the 1st (first) order diffraction. In the typical prior art lenses discussed above, a step height equivalent to slightly more than 3 microns was chosen to evenly divide the first and zero order diffraction gradients, thereby causing about 40% of the light to be focused at a near focal length and about 40% of the light to be focused at a far focal length. The overall efficiency is thus about 80%. However, in the lenses of the present invention, a step height of about 6 microns is chosen. As clearly seen in Fig. 1, at this step height, almost 100% of the incident light is diffracted at the first order. Thus, almost 100% of the light can be focused at either the near or the far focal length. By providing alternating 100% efficiency sectors, some focused for near and some for far, a nearly 100%

efficient lens is achieved.

A plan view of an embodiment of a lens made in accordance with the present invention is depicted in FIG. 2. The lens may either be utilized in a contact lens or in an intraocular lens, therefore, unrelated features such as the haptics used to secure an intraocular lens in the eye are not shown. Bifocal vision is preferably achieved by providing a lens, such as a biconvex diffractive lens, which has a basic power and creating high efficiency diffractive zones 10,12 which provide additive diffractive power to the basic lens power. It will be understood that the term "additive power" refers to the arithmetic addition of the power of the lens elements, therefore, in some embodiments, the diffractive power may be negative and reduce the overall power of that zone.

As shown, in one preferred arrangement it is desirable to place a circular diffractive zone 10 at approximately the center axis of the lens and dispose a second diffractive zone 12 in an annular spaced relationship with the first. Lying between the diffractive zones 10,12 are refractive zones 20,22, which possess the basic lens power only. Therefore, a portion of the incident light will fall upon the refractive zones 20,22 and provide focus at a first focal length. The optical efficiency of this zone will be the same as the optical efficiency of the basic lens, and if made to the highest commercial standards, will approach 100%. Another portion of the incident light will fall upon the diffractive zones 10,12 and also pass through the basic lens. Thus, the power of this portion of the lens will be the additive sum of the diffractive and refractive powers and will provide focus at a second focal length. The highest commercially available techniques for imparting a diffractive element are utilized to create the diffractive zones 10,12, thereby providing about 98% efficiency. As a result, the performance of the overall lens approaches 100% efficiency.

In a typical intraocular lens application, lenses such as that depicted in FIG. 2 will have an overall diameter of about 7.0 millimeters (mm). Most preferably, the innermost diffractive zone 10 will have a diameter of about 1.72 mm, the first refractive zone 20 will have an outside diameter of about 2.90 mm, the next diffractive zone will have an outside diameter of about 4.60 mm and the second refractive zone will have an outside diameter of about 7.00 mm. As will be understood by those of ordinary skill, the design dimensions may be varied somewhat to achieve particular corrective effects. It will also be understood that the order of placement of the diffractive and refractive zones may be reversed, i.e., the central zone may be refractive, etc.

Another embodiment of a lens having similar properties to that shown in FIG. 2 is depicted in FIG. 3. The lens design shown has a centrally disposed first refractive zone 30, preferably of about 1.3 mm diameter if used in a 7.00 mm intraocular lens. Surrounding the first refractive zone 30 is a diffractive zone 40, which preferably has an outer diameter of about 3.36 mm. A second refractive zone 32 surrounds the diffractive zone 40 and has an outer diameter of about 7.00 mm. As set forth above, in certain embodiments it may be desirable to alter the dimensions given or to reverse the arrangement of the zones.

Referring now to FIG. 4, an embodiment of a high efficiency lens utilizing both diffractive and refractive elements over its entire surface to achieve bifocal vision is shown. The lens depicted in FIG. 4 has two zones of a first diffractive power 110,112 for distance vision and two zones of a second diffractive power 120,122 for near vision. Although the layout of the zones shown places the zones in a series of annular rings, it should be understood that numerous other layouts are comprehended by the present invention. Also, as demonstrated with reference to FIGS. 2-3, the number of zones may be expanded or reduced. In this embodiment of the present invention, two zones of different diffractive powers are placed in an additive manner relative to a lens having a basic power to achieve multiple focal points. As will be readily understood by those of ordinary skill, the layout, shape and relative size of the zones is dependent upon the specific correction required.

In a preferred embodiment of the lens depicted in FIG. 4, a lens preferably provides a basic refractive power of about 10 diopters, achieved using a bi-convex lens or other lens designs known to those of ordinary skill. An additional 10 diopters of a first diffractive power is added by two diffractive zones 110,112, thereby providing a total power of 20 diopters for distance vision. Two near vision diffractive zones 120,122 which have a second diffractive power of about 14 diopters are also provided, resulting in a total near vision power of 24 diopters.

Referring now to FIGS. 5-6, intraocular lenses 200 made in accordance with the present invention are shown. The lenses 200 have haptics 210 for holding the lens in place. As shown, each lens has near vision N and far vision F zones. In accordance with one aspect of the present invention, either the near or the far zone may comprise a high efficiency diffractive element while the other zone comprises a refractive element of the basic lens. Alternatively, as discussed with reference to FIG. 4, in certain embodiments of the present invention, both the near and far zones will comprise diffractive elements, each respectively of a different diffractive power.

The lenses depicted in FIGS. 5-6 also illustrate further variations of the geometries of the zones of different focal lengths created on the basic lens. As shown in FIGS. 2-4, it will be desirable in certain instances to create one or more circular or annular diffractive zones. As shown in FIGS. 5-6, it is also possible to divide the lens diametrically in halves or quarters, alternating the near and far vision zones accordingly. As will be readily understood by those of ordinary skill, the same zone layouts depicted in FIGS. 2-6 may be applied to contact lenses and other forms of lenses and are not limited to

intraocular lenses.

The operation of an intraocular lens 200 within the eye 250 is shown in FIG. 7. Light from a near object N is focused on the retina R by the near vision zone. Light from a far object F is focused on the retina R by the far vision zone of the lens. Therefore, all of the light both the near and far objects is focused by the near or far zone respectively, resulting in a nearly 100% efficient lens.

Similarly, FIG. 8 depicts a contact lens 100 made in accordance with the present invention disposed on the cornea of an eye 250. Unlike the example of FIG. 7, the patient wearing a corrective contact lens also has a natural crystalline lens 260 within the eye.

As will be understood by those of ordinary skill the lenses discussed above may have a basic refractive power provided by the shape of the lens. The present invention may be applied to bi-convex or plano convex lenses, as well as to meniscus lenses, such as contact lenses.

Although certain embodiments of the present invention have be set forth in detail, these examples are not meant to be limiting. Numerous other embodiments and variations to the embodiments set forth will immediately present themselves to those of ordinary skill. Accordingly, reference should be made to the appended claims in order to determine the scope of the present invention.

Claims

1. A multifocal lens for correcting vision comprising:

   a basic lens element (20,22) having a basic lens power and a basic focal length; and
   one or more diffractive elements (10,12) covering one or more zones of said basic lens element and having a diffractive power which results in a specific intensity distribution of light at various order foci of the covered zones,
   whereby a portion of the light travelling through said lens is focused at said basic focal length by said basic lens power, and another portion of the light travelling through said lens is focused at a different focal length by the combined power of said basic lens element and said diffractive elements, said lens being characterised in that:
   at least one of said one or more diffractive elements (10,12) has a step height chosen so that the intensity of light concentrated in the first order diffractive focal point is greater than the intensity of light concentrated in the zeroth order diffractive focal point and so that the aggregate efficiency of the zeroth and first order diffractions is greater than 85%.

2. The lens of claim 1 wherein said one or more diffractive elements (10,12) have a step height chosen so as to afford an efficiency of about 100% to said lens.

3. The lens of claim 1 or claim 2, wherein said diffractive zones (10,12) are arrayed in a substantially annular pattern.

4. The lens of claim 3, wherein said diffractive element comprises an annular zone (40) having an inner diameter greater than zero and an outer diameter less than the diameter of said lens.

5. The lens of claim 4, wherein the inner diameter of said diffractive element (40) is about 1.30 millimeters and the outer diameter is about 3.36 millimeters.

6. The lens of claim 3, wherein said diffractive element comprises a circular zone (10) disposed at about the geometric center of the lens and a annular zone (12) having an inner diameter greater than zero and an outer diameter less than the diameter of said lens.

7. The lens of claim 6, wherein the diameter of said circular zone (10) is about 1.72 millimeters, and the inner diameter of said diffractive element (12) is about 2.90 millimeters and the outer diameter is about 4.60 millimeters.

8. The lens according to any preceding claim, wherein said diffractive zones have a diffractive power of greater than about 2 diopters.

9. The lens of any preceding claim, wherein said diffractive elements (10,12,40) comprise Fresnel zone plate elements.

10. The lens of any preceding claim, wherein said diffractive elements (10,12,40) comprise holographic elements.

11. A multifocal lens for correcting vision comprising:

    a basic lens element having a basic lens power and a basic focal length;
    one or more first diffractive elements (110,112) covering one or more zones of said basic lens element and having a first diffractive power which results in a specific intensity distribution of light at various order foci of the covered zones; and
    one or more second diffractive elements (120,122) covering one or more zones of said basic lens element and having a second diffractive power which results in a specific intensity distribution of light at various order foci of the

covered zones,

whereby a first portion of the light travelling through said lens is focused at a first focal length by the combined power of said basic lens element and said first diffractive elements, and another portion of the light travelling through said lens is focused at a second focal length by the combined power of said basic lens element and said second diffractive elements, said lens being characterised in that:

at least one of said one or more first diffractive elements has a step height chosen so that the intensity of light concentrated in the first order diffractive focal point of said first diffractive element is greater than the intensity of light concentrated in the zeroth order diffractive focal point of said first diffractive element, and so that the aggregate efficiency of the zeroth and first order diffractions of said first diffractive element is greater than 85%, and

at least one of said one or more second diffractive elements has a step height chosen so that the intensity of light concentrated in the first order diffractive focal point of said second diffractive element is greater than the intensity of light concentrated in the zeroth order diffractive focal point of said second diffractive element, and so that the aggregate efficiency of the zeroth and first order diffractions of said second diffractive element is greater than 85%.

12. The lens of claim 11 wherein said one or more first diffractive elements (110,112) and said one or more second diffractive elements (120,122) have a step height chosen so as to afford an efficiency of about 100% to said lens.

13. The lens of claim 11 or claim 12, wherein said diffractive zones (110,112,120,122) are arrayed in a substantially annular pattern.

14. The lens of claim 13, wherein said diffractive element (110,112,120,122) comprises an annular zone having an inner diameter greater than zero and an outer diameter less than the diameter of said lens.

15. The lens of claim 11 or claim 12, wherein said diffractive element (110,112,120,122) comprises a circular zone disposed at about the geometric center of the lens and a annular zone having an inner diameter greater than zero and an outer diameter less than the diameter of said lens.

16. The lens of any of claims 1, 2, 11 or 12, wherein said diffractive zones are arranged as alternate semi-circular areas.

17. The lens of any of claims 1, 2, 11 or 12, wherein said diffractive zones are arrayed as alternating quarter circular areas.

18. The lens of any preceding claim, wherein said lens is an intraocular lens.

19. The lens of any preceding claim, wherein said basic power is provided by refraction.

20. The lens of claim 19, wherein said basic lens element comprises a biconvex lens.

21. The lens of clam 19, wherein said basic lens element comprises a meniscus lens.

22. The lens of claim 19, wherein said basic lens element comprises a plano-convex lens.

23. The lens of any of claims 1 to 17, wherein said lens is a contact lens.

24. The lens of any preceding claim, wherein said step height is about 6 microns.

Patentansprüche

1. Multifokallinse zur Korrektur des Sehvermögens, welche umfaßt:

- ein Grundlinsenelement (20, 22) mit einer Grundlinsenstärke und einer Grundbrennweite und
- eine oder mehrere Beugungselemente (10, 12), welche eine oder mehrere Zonen des Grundlinsenelements überdecken und eine Beugungstärke besitzen, welche zu einer spezifischen Lichtintensitätsverteilung bei Brennpunkten verschiedener Ordnung der überdeckten Zonen führt,

wobei ein Teil des Lichts, welches durch die Linse läuft, bei der Grundbrennweite durch die Grundlinsenstärke fokussiert wird und ein anderer Teil des Lichts, welches durch die Linse läuft, bei einer anderen Brennweite durch die kombinierte Stärke des Grundlinsenelements und der Beugungselemente fokussiert wird, wobei die Linse dadurch gekennzeichnet ist, daß zumindest ein Beugungselement von den besagten ein oder mehreren Beugungselementen (10, 12) eine Stufenhöhe aufweist, die so gewählt ist, daß die Intensität des Lichts, das in dem Beugungsbrennpunkt erster Ordnung konzentriert wird, größer als die Intensität des Lichts ist, das in dem Beugungsbrennpunkt nullter Ordnung konzentriert wird, und der kombinierte Wirkungsgrad der Beugung nullter und

erster Ordnung größer als 85 % ist.

2. Linse nach Anspruch 1, bei der die einen oder mehreren Beugungselemente (10, 12) eine Stufenhöhe aufweisen, die so gewählt ist, daß ein Wirkungsgrad der Linse von ungefähr 100 % ermöglicht wird.

3. Linse nach Anspruch 1 oder Anspruch 2, bei der die Beugungszonen (10, 12) in einem im wesentlichen ringförmigen Muster angeordnet sind.

4. Linse nach Anspruch 3, bei der das Beugungselement eine ringförmige Zone (40) mit einem Innendurchmesser größer als null und einem Außendurchmesser kleiner als der Durchmesser der Linse aufweist.

5. Linse nach Anspruch 4, bei welcher der Innendurchmesser des Beugungselements (40) ungefähr 1,3 mm und der Außendurchmesser ungefähr 3,36 mm beträgt.

6. Linse nach Anspruch 3, bei der das Beugungselement eine kreisförmige Zone (10), die ungefähr im geometrischen Zentrum der Linse angeordnet ist, und eine ringförmige Zone (12) mit einem Innendurchmesser größer als null und einem Außendurchmesser kleiner als der Durchmesser der Linse aufweist.

7. Linse nach Anspruch 6, bei welcher der Durchmesser der kreisförmigen Zone (10) ungefähr 1,72 mm beträgt und der Innendurchmesser des Beugungselements (12) ungefähr 2,9 mm und der Außendurchmesser ungefähr 4,6 mm beträgt.

8. Linse nach einem der vorangehenden Ansprüche, bei der die Beugungszonen eine Beugungsstärke von mehr als ungefähr 2 Dioptrien aufweisen.

9. Linse nach einem der vorangehenden Ansprüche, bei der die Beugungselemente (10, 12, 40) Fresnelzonenplatten-Elemente umfassen.

10. Linse nach einem der vorangehenden Ansprüche, bei der die Beugungselemente (10, 12, 40) holographische Elemente umfassen.

11. Multifokallinse zur Korrektur des Sehvermögens, welche umfaßt:

- ein Grundlinsenelement mit einer Grundlinsenstärke und einer Grundbrennweite,
- eine oder mehrere erste Beugungselemente (110, 112), welche eine oder mehrere Zonen des Grundlinsenelements überdecken und eine erste Beugungsstärke aufweisen, die zu einer spezifischen Intensitätsverteilung des Lichts bei Brennpunkten verschiedener Ordnung der überdeckten Zonen führt und
- eine oder mehrere zweite Beugungselemente (120, 122), welche eine oder mehrere Zonen des Grundlinsenelements überdecken und eine zweite Beugungsstärke aufweisen, die zu einer spezifischen Intensitätsverteilung des Lichts bei Brennpunkten verschiedener Ordnung der überdeckten Zonen führt,

wobei ein erster Teil des Lichts, welches durch die Linse läuft, bei einer ersten Brennweite durch die kombinierte Stärke des Grundlinsenelements und der ersten Beugungselemente fokussiert wird und ein weiterer Teil des Lichts, welches durch die Linse läuft, bei einer zweiten Brennweite durch die kombinierte Stärke des Grundlinsenelements und der zweiten Beugungselemente fokussiert wird,
wobei die Linse dadurch gekennzeichnet ist, daß
zumindest ein Beugungselement von den besagten ein oder mehreren ersten Beugungselementen eine Stufenhöhe aufweist, die so gewählt ist, daß die Intensität des Lichts, welches in dem Beugungsbrennpunkt erster Ordnung des ersten Beugungselements konzentriert wird, größer als die Intensität des Lichts ist, welches in dem Beugungsbrennpunkt nullter Ordnung des ersten Beugungselements konzentriert wird, und der kombinierte Wirkungsgrad der Beugungen nullter und erster Ordnung des ersten Beugungselements größer als 85 % ist und
zumindest ein Beugungselement von den besagten ein oder mehreren zweiten Beugungselementen eine Stufenhöhe aufweist, die so gewählt ist, daß die Intensität des Lichts, welches in dem Beugungsbrennpunkt erster Ordnung des zweiten Beugungselements konzentriert wird, größer als die Intensität des Lichts ist,
welches in dem Beugungsbrennpunkt nullter Ordnung des zweiten Beugungselements konzentriert wird, und der kombinierte Wirkungsgrad der Beugung nullter und erster Ordnung des zweiten Beugungselements größer als 85 % ist.

12. Linse nach Anspruch 11, bei der die besagten ein oder mehreren ersten Beugungselemente (110, 112) und die besagten ein oder mehreren zweiten Beugungselemente (120, 122) eine Stufenhöhe aufweisen, welche so gewählt ist, daß ein Wirkungsgrad der Linse von ungefähr 100 % ermöglicht wird.

13. Linse nach Anspruch 11 oder Anspruch 12, bei der

die Beugungszonen (110, 112, 120, 122) in einem im wesentlichen ringförmigen Muster angeordnet sind.

14. Linse nach Anspruch 13, bei der das Beugungselement (110, 112, 120, 122) eine ringförmige Zone mit einem Innendurchmesser größer als null und einem Außendurchmesser kleiner als der Durchmesser der Linse aufweist.

15. Linse nach Anspruch 11 oder Anspruch 12, bei der das Beugungselement (110, 112, 120, 122) eine kreisförmige Zone, die ungefähr im geometrischen Zentrum der Linse angeordnet ist, und eine ringförmige Zone mit einem Innendurchmesser größer als null und einem Außendurchmesser kleiner als der Innendurchmesser der Linse umfaßt.

16. Linse nach einem der Ansprüche 1, 2, 11 oder 12, bei der die Beugungszonen als alternierende halbkreisförmige Flächen angeordnet sind.

17. Linse nach einem der Ansprüche 1, 2, 11 oder 12, bei der die Beugungszonen als alternierende viertelkreisförmige Flächen angeordnet sind.

18. Linse nach einem der vorangehenden Ansprüche, wobei die Linse eine intraokuläre Linse ist.

19. Linse nach einem der vorangehenden Ansprüche, wobei die Grundstärke durch Brechung erzeugt wird.

20. Linse nach Anspruch 19, wobei das Grundlinsenelement eine bikonvexe Linse umfaßt.

21. Linse nach Anspruch 19, wobei das Grundlinsenelement eine Meniskuslinse umfaßt.

22. Linse nach Anspruch 19, wobei das Grundlinsenelement eine plankonvexe Linse umfaßt.

23. Linse nach einem der Ansprüche 1 bis 17, wobei die Linse eine Kontaktlinse ist.

24. Linse nach einem der vorangehenden Ansprüche, wobei die Stufenhöhe ungefähr 6 μm beträgt.

Revendications

1. Lentille à foyers multiples de correction de la vision, comprenant :

un élément de lentille de base (20, 22) ayant un pouvoir de lentille de base et une distance focale de base ; et
un ou plusieurs éléments de diffraction (10, 12) recouvrant une ou plusieurs zones dudit élément de lentille de base et ayant un pouvoir de diffraction qui a pour conséquence une distribution spécifique de l'intensité de la lumière en des foyers de divers ordres des zones recouvertes,
de manière qu'une partie de la lumière passant à travers ladite lentille soit focalisée à ladite distance focale de base par ledit pouvoir de base de la lentille et qu'une autre partie de la lumière passant à travers ladite lentille soit focalisée à une distance focale différente par le pouvoir combiné dudit élément de lentille de base et desdits éléments de diffraction, ladite lentille étant caractérisée en ce que :
au moins un dudit un ou plusieurs éléments de diffraction (10, 12) a une hauteur de gradin qui est choisie de la manière que l'intensité de la lumière concentrée au point focal de diffraction du premier ordre soit supérieure à l'intensité de la lumière concentrée au point focal de diffraction de l'ordre zéro et de manière que le rendement global des diffractions de l'ordre zéro et du premier ordre soit supérieur à 85%.

2. Lentille selon la revendication 1, dans laquelle ledit un ou plusieurs éléments de diffraction (10, 12) ont une hauteur de gradin choisie de manière à conférer un rendement d'environ 100% à ladite lentille.

3. Lentille selon la revendication 1 ou la revendication 2, dans laquelle lesdites zones de diffraction (10, 12) sont disposées suivant un motif sensiblement annulaire.

4. Lentille selon la revendication 3, dans laquelle ledit élément de diffraction comprend une zone annulaire (40) ayant un diamètre intérieur qui est supérieur à zéro et un diamètre extérieur qui est inférieur au diamètre de ladite lentille.

5. Lentille selon la revendication 4, dans laquelle le diamètre intérieur dudit élément de diffraction (40) est d'environ 1,30 millimètre et le diamètre extérieur est d'environ 3,36 millimètres.

6. Lentille selon la revendication 3, dans laquelle ledit élément de diffraction comprend une zone circulaire (10) disposée à peu près au centre géométrique de la lentille et une zone annulaire (12) ayant un diamètre intérieur qui est supérieur à zéro et un diamètre extérieur qui est inférieur au diamètre de ladite lentille.

7. Lentille selon la revendication 6, dans laquelle le diamètre de ladite zone circulaire (10) est d'environ 1,72 millimètre et le diamètre intérieur dudit élément de diffraction (12) est d'environ 2,90 millimètres et

le diamètre extérieur est d'environ 4,60 millimètres.

8. Lentille selon l'une quelconque des revendications précédentes, dans laquelle lesdites zones de diffraction ont un pouvoir de diffraction supérieur à environ 2 dioptries.

9. Lentille selon l'une quelconque des revendications précédentes, dans laquelle lesdits éléments de diffraction (10, 12, 40) consistent en des éléments de plaque formant des zones de Fresnel.

10. Lentille selon l'une quelconque des revendications précédentes, dans laquelle lesdits éléments de diffraction (10, 12, 40) consistent en éléments holographiques.

11. Lentille à foyers multiples de correction de la vision, comprenant :

un élément de lentille de base ayant un pouvoir de lentille de base et une distance focale de base ;
un ou plusieurs premiers éléments de diffraction (110, 112) recouvrant une ou plusieurs zones dudit élément de lentille de base et ayant un premier pouvoir de diffraction qui a pour conséquence une distribution spécifique de l'intensité de la lumière en des foyers de divers ordres des zones recouvertes ; et
un ou plusieurs deuxièmes éléments de diffraction (120, 122) recouvrant une ou plusieurs zones dudit élément de lentille de base et ayant un deuxième pouvoir de diffraction qui a pour conséquence une distribution spécifique de l'intensité de la lumière en des foyers d'ordres divers des zones recouvertes,
une première partie de la lumière passant à travers ladite lentille étant focalisée à une première distance focale par le pouvoir combiné dudit élément de lentille de base et desdits premiers éléments de diffraction et une autre partie de la lumière qui passe à travers ladite lentille étant focalisée à une deuxième distance focale par le pouvoir combiné dudit élément de lentille de base et desdits deuxièmes éléments de diffraction, ladite lentille étant caractérisée en ce que :
au moins l'un dudit un ou plusieurs premiers éléments de diffraction a une hauteur de gradin choisie de manière que l'intensité de la lumière concentrée au point focal de diffraction du premier ordre dudit premier élément de diffraction soit supérieure à l'intensité de la lumière concentrée au point focal de diffraction de l'ordre zéro dudit premier élément de diffraction et de manière que le rendement global des diffractions de l'ordre zéro et du premier ordre dudit premier élément de diffraction soit supérieur à 85% et
au moins l'un dudit un ou plusieurs deuxièmes éléments de diffraction a une hauteur de gradin choisie de manière que l'intensité de la lumière concentrée au point focal de diffraction du premier ordre dudit deuxième élément de diffraction soit supérieure à l'intensité de la lumière concentrée au point focal de diffraction de l'ordre zéro dudit deuxième élément de diffraction et de façon que le rendement global des diffractions de l'ordre zéro et du premier ordre dudit deuxième élément de diffraction soit supérieur à 85%

12. Lentille selon la revendication 11, dans laquelle ledit un ou plusieurs premiers éléments de diffraction (110, 112) et ledit un ou plusieurs deuxièmes éléments de diffraction (120, 122) ont une hauteur de gradin choisie de manière à conférer un rendement d'environ 100% à ladite lentille.

13. Lentille selon la revendication 11 ou la revendication 12, dans laquelle lesdites zones de diffraction (110, 112, 120, 122) sont disposées en un ensemble formant un motif sensiblement annulaire.

14. Lentille selon la revendication 13, dans laquelle ledit élément de diffraction (110, 112, 120, 122) consiste en une zone annulaire ayant un diamètre intérieur qui est supérieur à zéro et un diamètre extérieur qui est inférieur au diamètre de ladite lentille.

15. Lentille selon la revendication 11 ou la revendication 12, dans laquelle ledit élément de diffraction (110, 112, 120, 122) consiste en une zone circulaire disposée à peu près au centre géométrique de la lentille et une zone annulaire ayant un diamètre intérieur qui est supérieur à zéro et un diamètre extérieur qui est inférieur au diamètre de ladite lentille.

16. Lentille selon l'une quelconque des revendications 1, 2, 11 ou 12, dans laquelle lesdites zones de diffraction sont disposées en surfaces semi-circulaires alternantes.

17. Lentille selon l'une quelconque des revendications 1, 2, 11 ou 12, dans laquelle lesdites zones de diffraction sont disposées en un ensemble de surfaces alternantes en quart de cercle.

18. Lentille selon l'une quelconque des revendications précédentes, dans laquelle ladite lentille est une lentille intra-oculaire.

19. Lentille selon l'une quelconque des revendications précédentes, dans laquelle ledit pouvoir de base est produit par réfraction.

20. Lentille selon la revendication 19, dans laquelle ledit élément de lentille de base consiste en une lentille bi-convexe.

21. Lentille selon la revendication 19, dans laquelle ledit élément de lentille de base consiste en une lentille en forme de ménisque.

22. Lentille selon la revendication 19, dans laquelle ledit élément de lentille de base consiste en une lentille plane-convexe.

23. Lentille selon l'une quelconque des revendications 1 à 17, dans laquelle ladite lentille est une lentille de contact.

24. Lentille selon l'une quelconque des revendications précédentes, dans laquelle ladite hauteur de gradin est d'environ 6 microns.

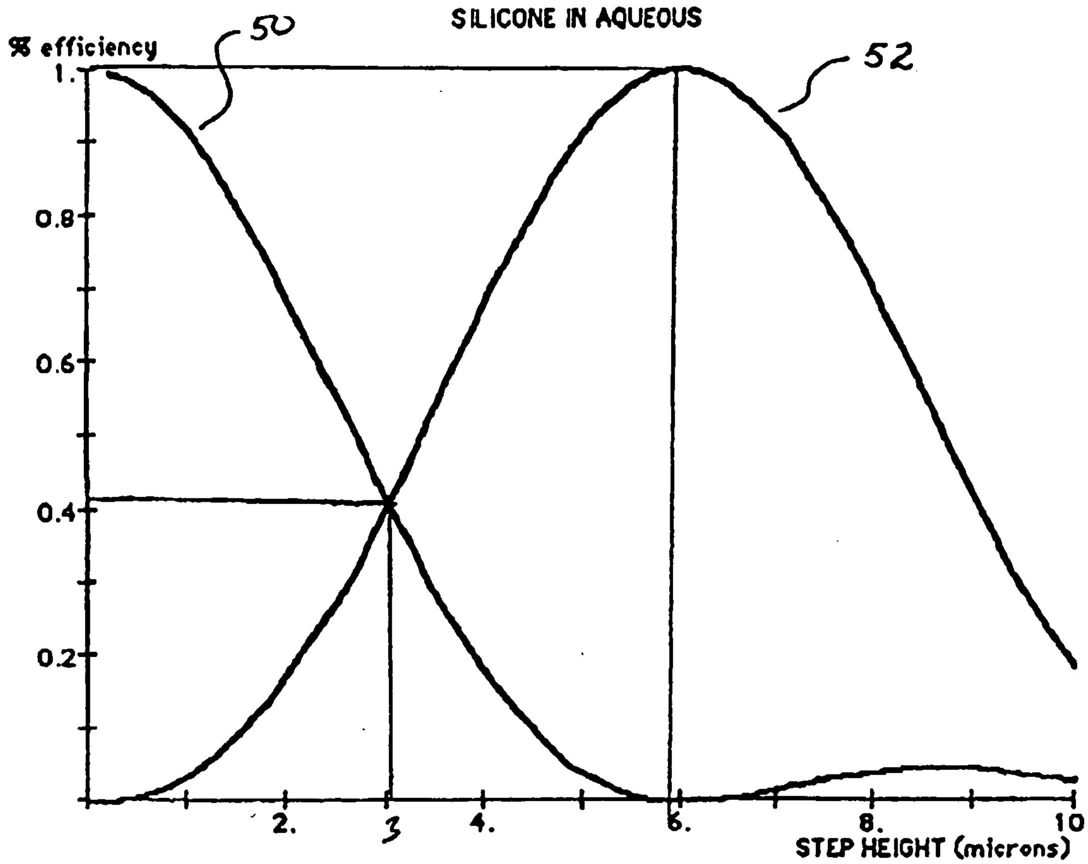
SILICONE IN AQUEOUS
% efficiency
50
52
1.
0.8
0.6
0.4
0.2
2.
3
4.
6.
8.
10.
STEP HEIGHT (microns)

FIG. 1

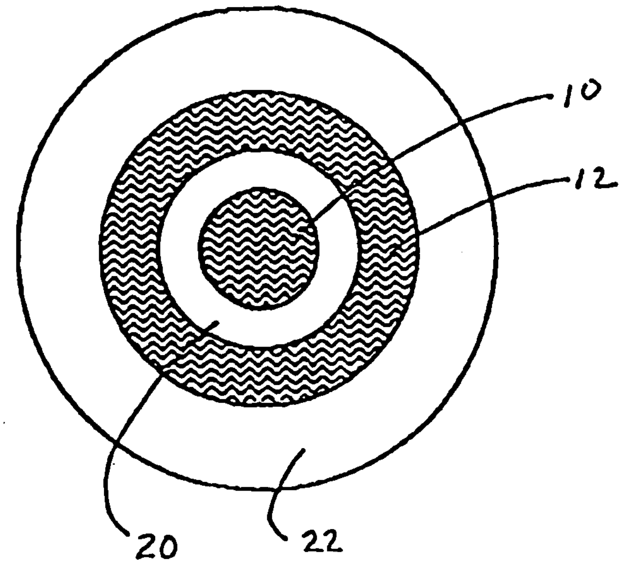

FIG. 2

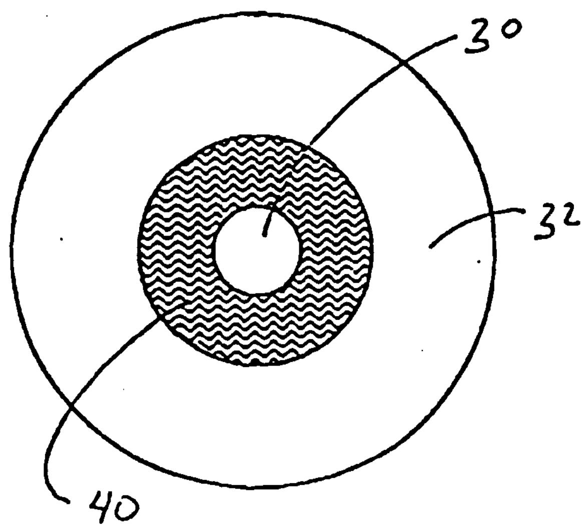

FIG. 3

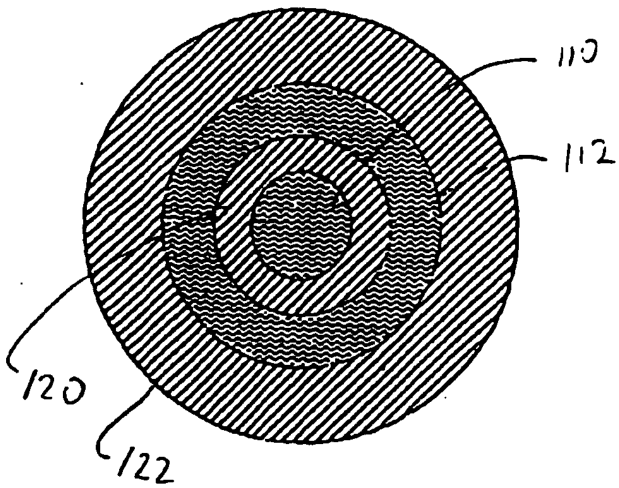

FIG. 4

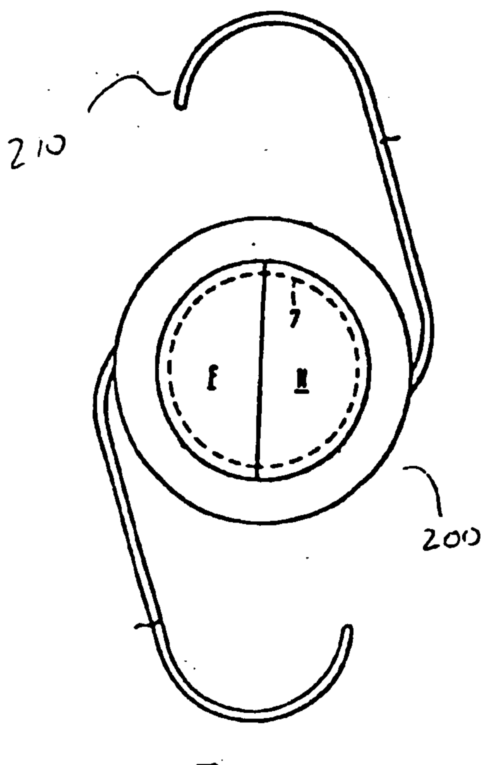

FIG. 5

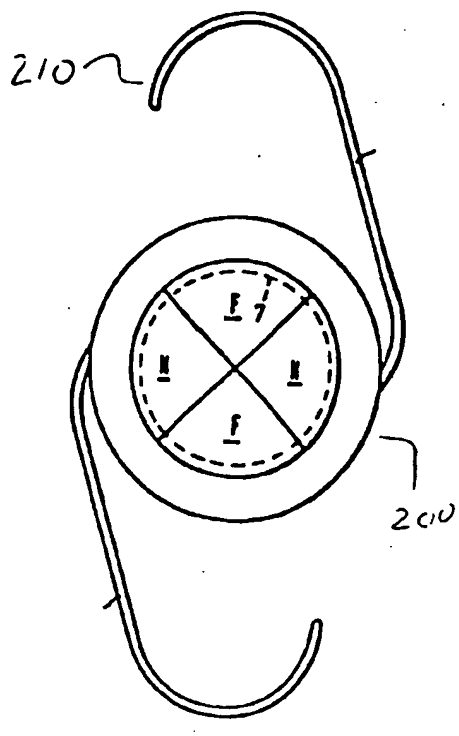

FIG. 6

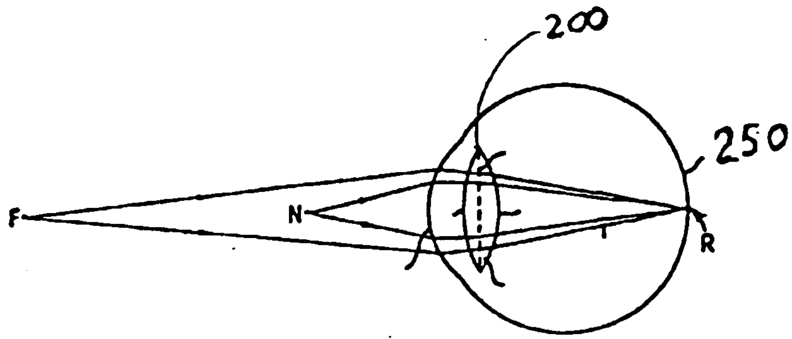

FIG. 7

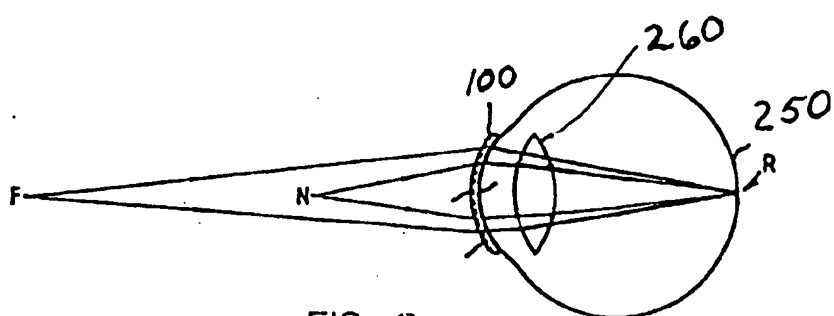

FIG. 8